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(54) **REDUCING THE EFFECT OF GLASS CHARGING IN MEMS DEVICES**

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(57) **ABSTRACT**

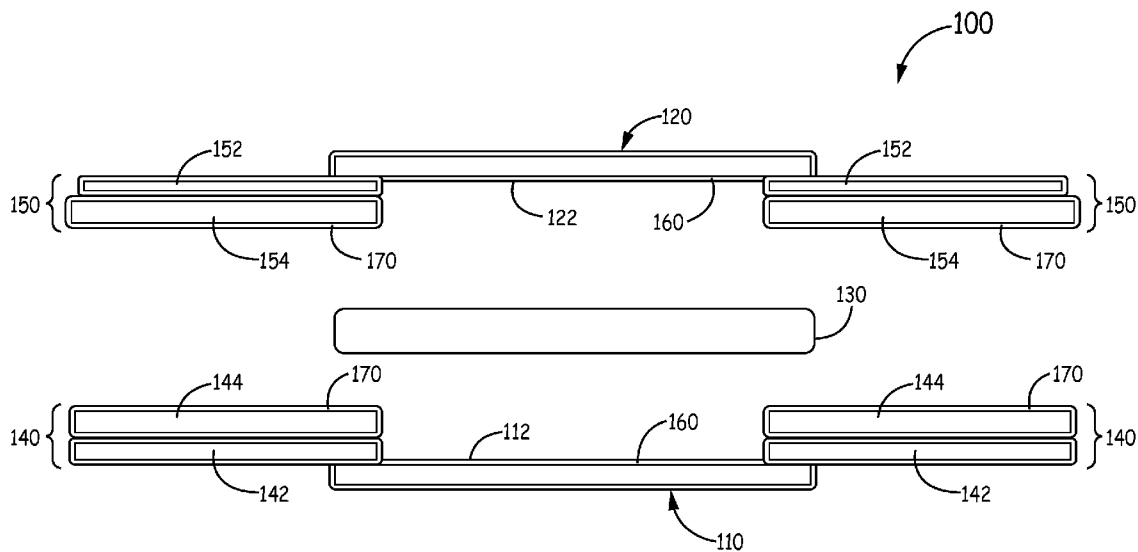
A method of controlling exposed glass charging in a micro-electro-mechanical systems (MEMS) device is disclosed. The method includes providing a MEMS device comprising a proof mass positioned apart from at least one sense plate and at least one outboard metallization layer, wherein at least one conductive glass layer is coupled to the sense plate and the outboard metallization layer, the conductive glass layer including at least one exposed glass portion near the proof mass; and applying a first voltage to the sense plate and a second voltage to the outboard metallization layer. The first voltage is separated from the second voltage by a predetermined voltage level such that the exposed glass portion has an average voltage corresponding to a voltage midway between the first voltage and the second voltage.

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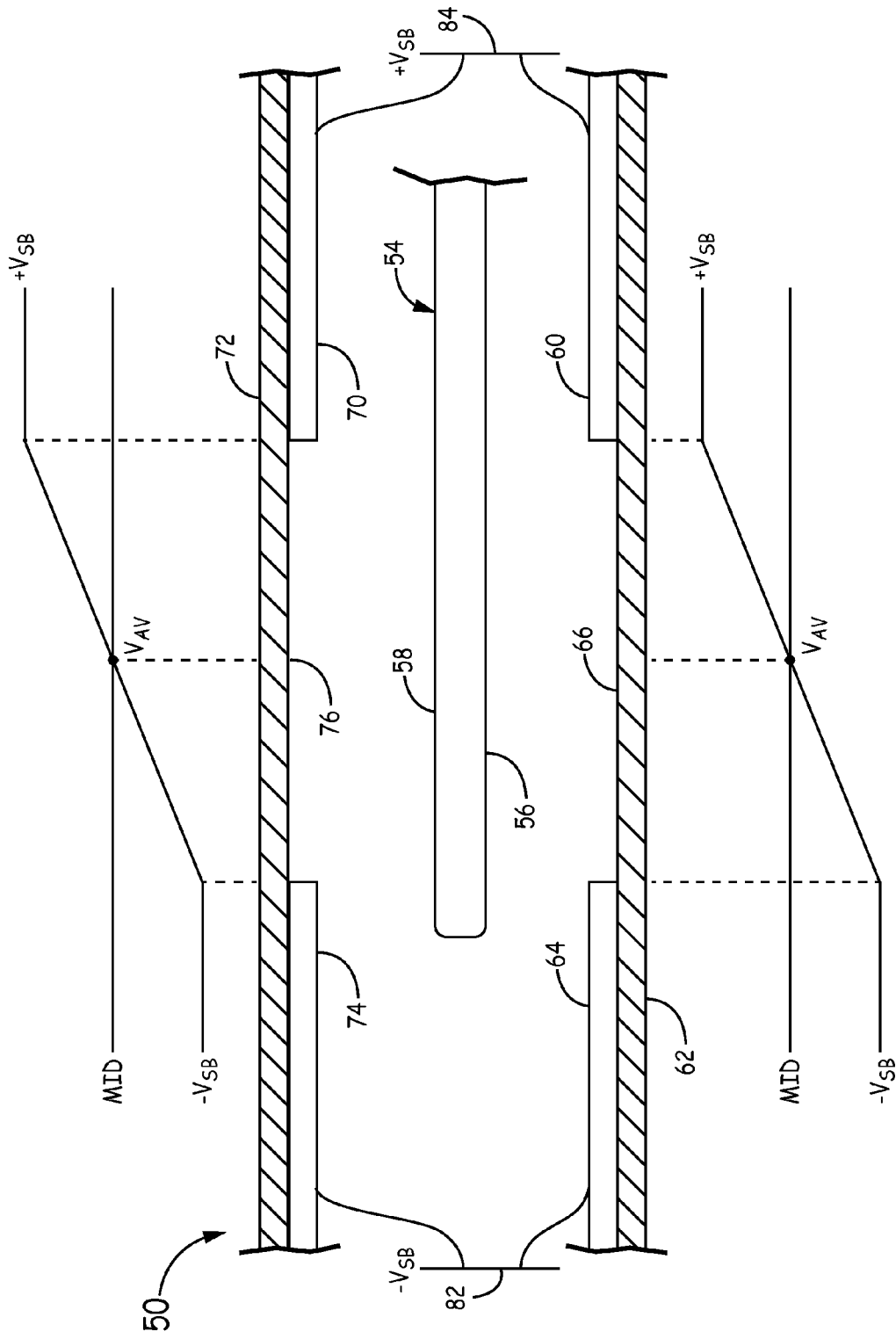


FIG. 1B

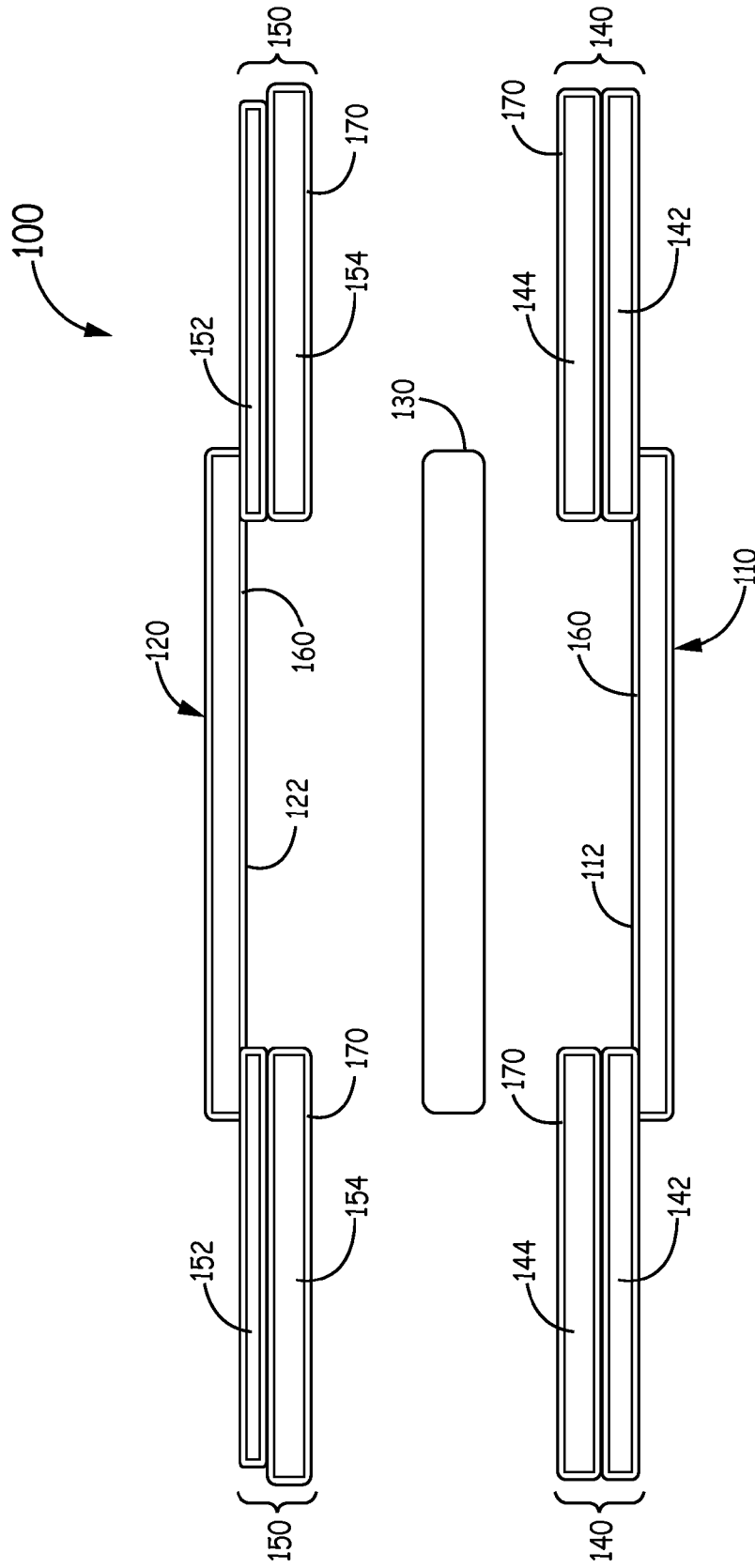


FIG. 2

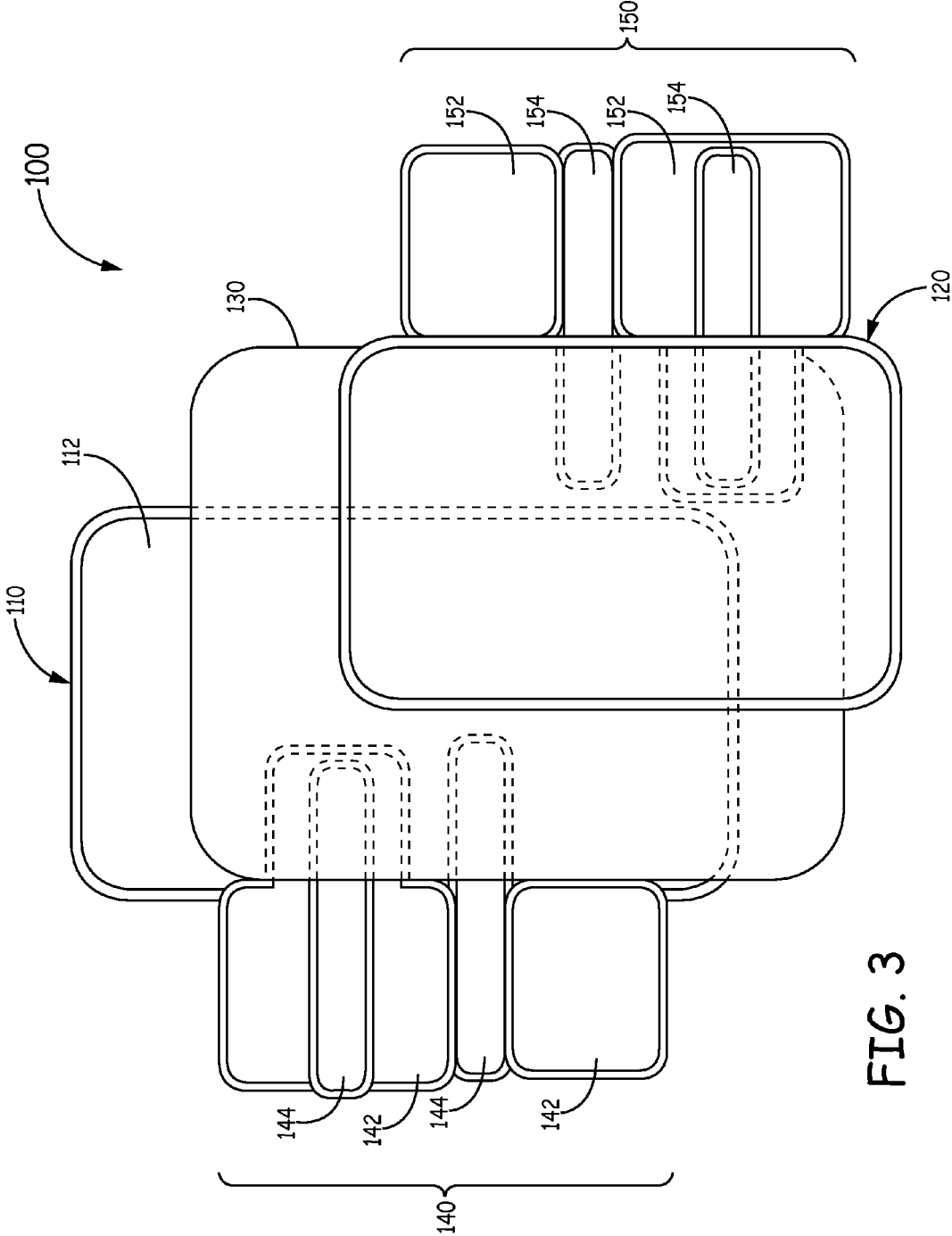


FIG. 3

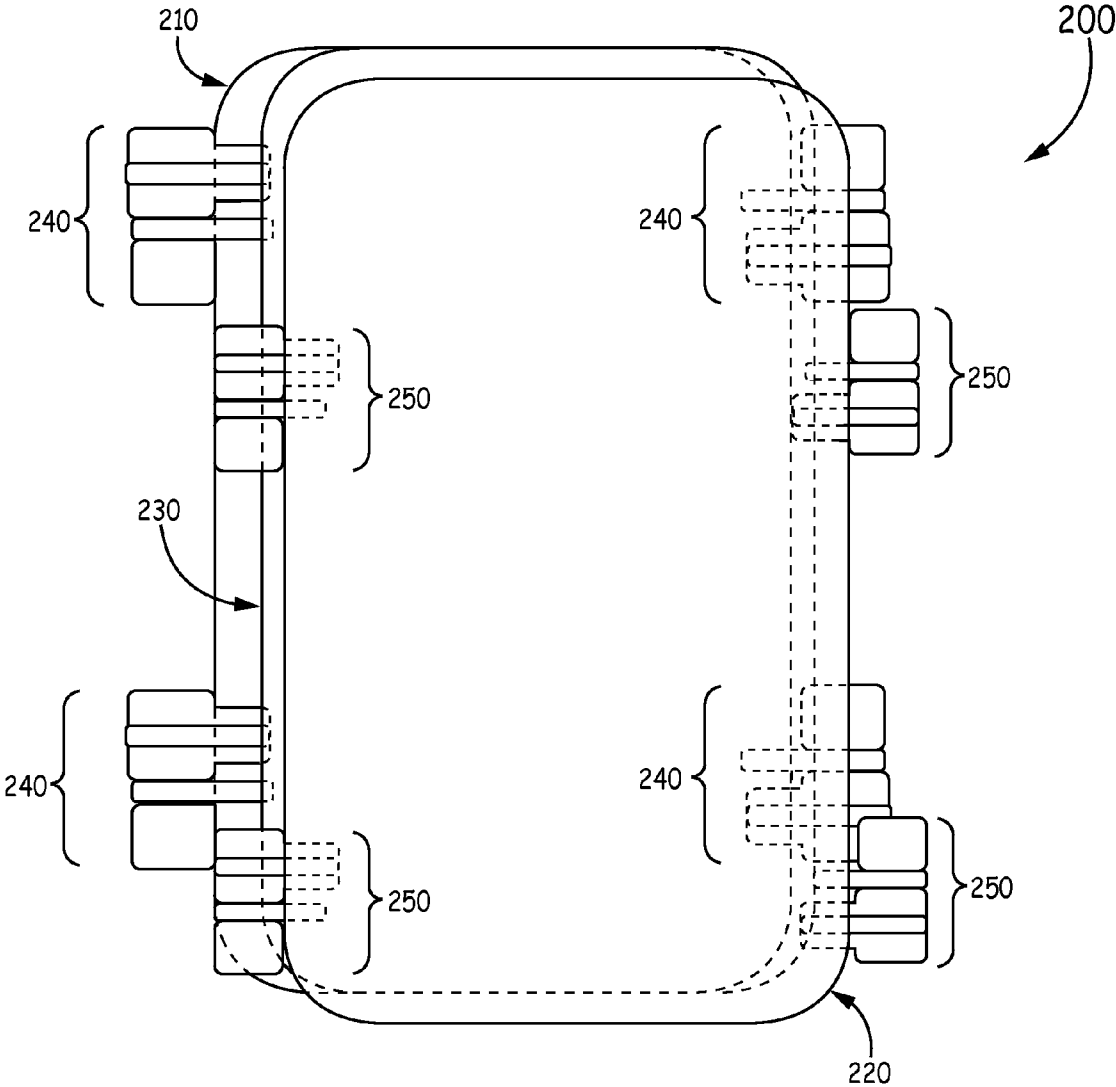


FIG. 4

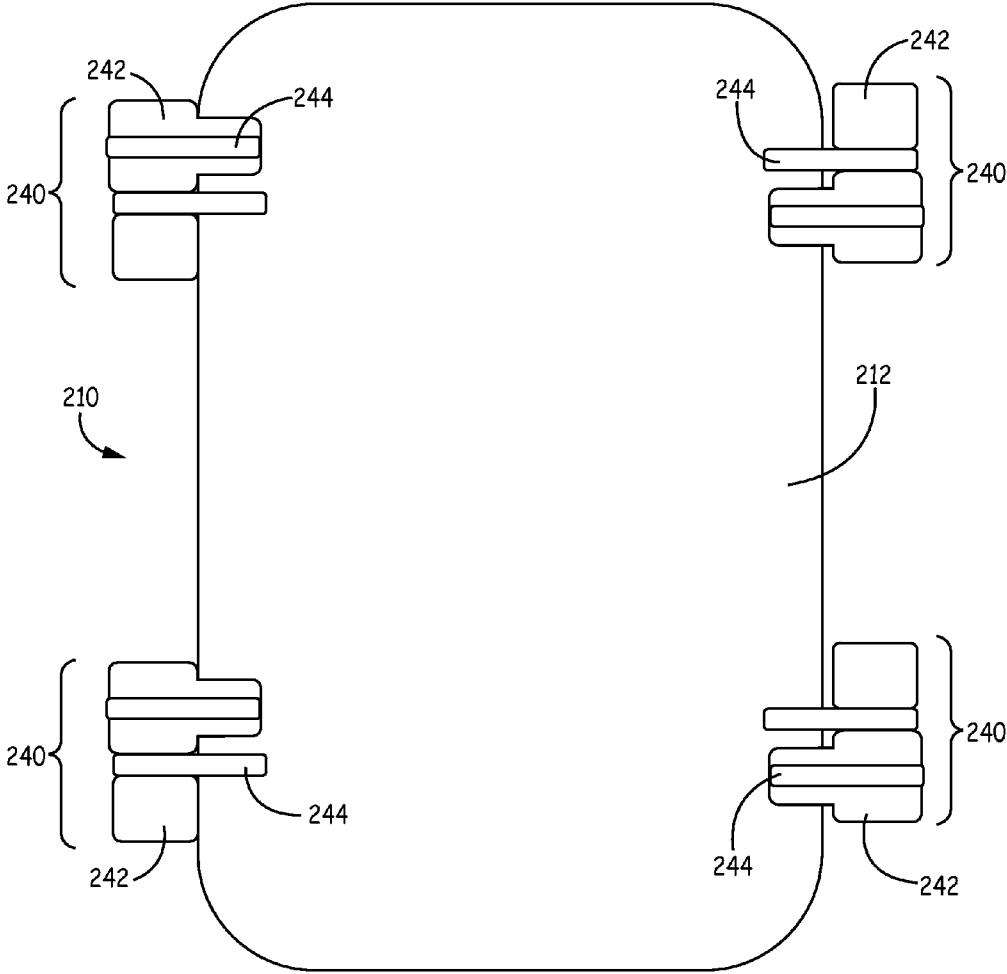


FIG. 5A

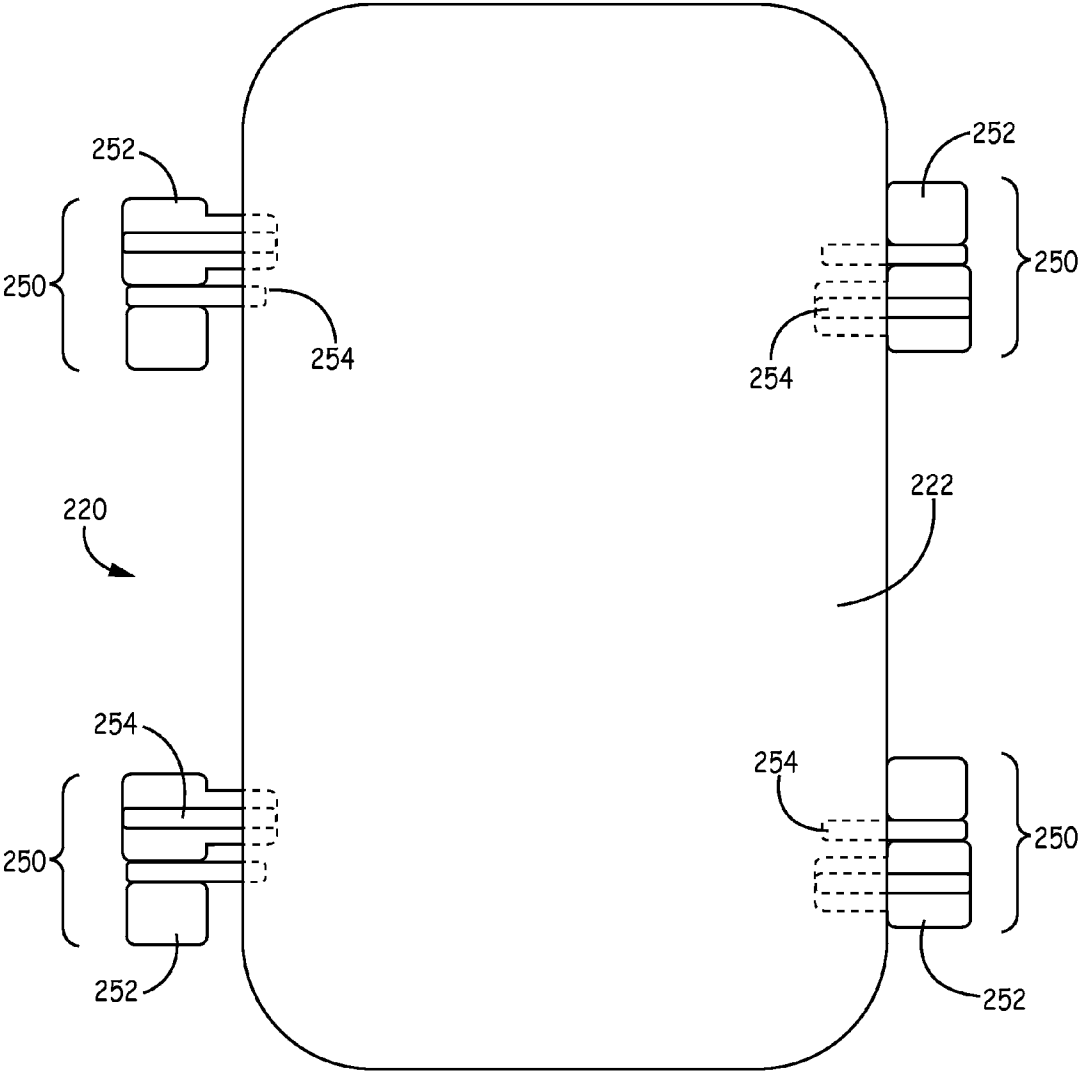


FIG. 5B

REDUCING THE EFFECT OF GLASS CHARGING IN MEMS DEVICES

BACKGROUND

[0001] Micro-Electro-Mechanical Systems (MEMS) devices can include various sensors, such as gyroscopes and accelerometers, which can be implemented in various inertial navigation and control system applications. A MEMS gyroscope or accelerometer may include microstructure sense elements such as a proof mass interposed between a pair of sense plates, forming a capacitive sensor.

[0002] Glass layers are often utilized as structures in MEMS devices. These glass layers are typically doped, which results in the glass having some conductivity, allowing electrical charges to flow and accumulate on the glass during operation of the MEMS devices. Sometimes it is convenient or necessary to allow uncovered glass to be exposed to the proof mass of a MEMS device such as in a capacitive MEMS sensor. As a result, the effective sensitivity of the device changes as charge is accumulated on the glass during operation. This makes the scale factor, bias, or other performance metrics of the MEMS sensor unreliable.

SUMMARY

[0003] A method of controlling exposed glass charging in a micro-electro-mechanical systems (MEMS) device includes providing a MEMS device comprising a proof mass positioned apart from at least one sense plate and at least one outboard metallization layer, wherein at least one conductive glass layer is coupled to the sense plate and the outboard metallization layer, the conductive glass layer including at least one exposed glass portion near the proof mass; and applying a first voltage to the sense plate and a second voltage to the outboard metallization layer. The first voltage is separated from the second voltage by a predetermined voltage level such that the exposed glass portion has an average voltage corresponding to a voltage midway between the first voltage and the second voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Understanding that the drawings depict only exemplary embodiments and are not therefore to be considered limiting in scope, the exemplary embodiments will be described with additional specificity and detail through the use of the accompanying drawings, in which:

[0005] FIG. 1A is a schematic depiction of a MEMS device and voltage diagram, which illustrate the present technique according to one embodiment;

[0006] FIG. 1B is a schematic depiction of a MEMS device and voltage diagrams, which illustrate the present technique according to another embodiment;

[0007] FIG. 2 is an end view of a MEMS device according to another embodiment;

[0008] FIG. 3 is a top view of a MEMS device according to another embodiment;

[0009] FIG. 4 is a top view of a MEMS device according to another embodiment;

[0010] FIG. 5A illustrates a first sense plate of the MEMS device of FIG. 4; and

[0011] FIG. 5B illustrates a second sense plate of the MEMS device of FIG. 4.

DETAILED DESCRIPTION

[0012] In the following detailed description, embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. It is to be understood that other embodiments may be utilized without departing from the scope of the invention. The following detailed description is, therefore, not to be taken in a limiting sense.

[0013] A method of controlling glass charging in a Micro-Electro-Mechanical Systems (MEMS) device is provided. The present approach allows for controlling the electrical charge of conductive exposed glass in a MEMS device resulting in the glass charging having no effect on sensor performance. The present technique does not stop the exposed glass from charging, but allows it to proceed in a balanced way so that it has no net effect on the sensor bias or scale factor over time. In this way, the performance of the MEMS device over time is unaffected by the time-varying potential of the exposed glass.

[0014] In general, the present method controls exposed glass potential levels so as to render them unimportant and not affecting sensor performance. For example, a first voltage is applied to the sense plate and a second voltage is applied to the outboard metallization layer, with the first voltage separated from the second voltage by a predetermined voltage level such that exposed glass has an average voltage corresponding to a voltage midway between the first voltage level and the second voltage level. This makes the average potential across the gap where the glass is exposed equal to MID (e.g., equal to the proof mass potential). With this average glass-charged voltage equal to that of the proof mass, it contributes no negative influence (degradation) on sensor performance.

[0015] In one embodiment, a sensor layout for the MEMS device is provided that eliminates the affect of glass charging without using an overlapping metal process.

[0016] The present approach is described in further detail hereafter with respect to the drawings. It should be noted that the exposed glass depicted in the drawings is not drawn to scale since the exposed glass is a very small fraction of the overall sense plate area. Most of the glass is "metallized" and only a small fraction of the glass is not covered, typically at a boundary that separates areas of different voltage potential in the MEMS device.

[0017] FIG. 1A is a schematic depiction of a MEMS device **10** according to one embodiment, which includes a voltage diagram illustrating one aspect of the present technique. The MEMS device **10** includes a proof mass **12** positioned over a sense plate **14** and an outboard metallization layer **16**. A glass layer **18** is coupled to sense plate **14** and outboard metallization layer **16**. The glass layer **18** is doped with conductive molecules (e.g., Na ions), which results in slightly conductive glass that aids in adhesion of sense plate **14** and outboard metallization layer **16** to glass layer **18**. An exposed glass portion **20** of glass layer **18** that is near proof mass **12** faces an edge portion **13** of proof mass **12**. When power is applied to MEMS device **10**, the exposed glass portion **20** slowly collects a charge and has a potential that changes over time. In contrast, the portions of glass layer **18** covered with metal achieve voltage potential immediately, because the metal conducts very well.

[0018] As shown in FIG. 1A, outboard metallization layer **16** is connected to a $-V_{SB}$ (voltage standby) line **22**, and sense plate **14** is connected to a $+V_{SB}$ line **24**. The proof mass **12** is connected to V_{mid} line **26** (voltage MID). This configuration results in the exposed glass portion **20** having an average

voltage (V_{AV}) equal to MID (e.g., zero ground), as illustrated in the voltage diagram. With both proof mass **12** and exposed glass portion **20** at the same potential, the effect of time-varying glass charging on the sensor capacitance is eliminated. Thus, the effects of glass charging on proof mass **12** are removed by controlling the voltages applied to sense plate **14** and outboard metallization layer **16**.

[0019] FIG. 1B is a schematic depiction of a MEMS device **50** according to another embodiment, which illustrates another aspect of the present technique. The MEMS device **50** generally includes a proof mass **54** positioned between a first sense plate **60** and a second sense plate **70**. The first sense plate **60** is attached to a first glass layer **62**, and a first outboard metallization layer **64** is attached to glass layer **62**. The glass layer **62** is doped with conductive molecules to aid in the attachment of sense plate **60** and metallization layer **64**. An exposed glass portion **66** of glass layer **62** faces a first edge surface **56** of proof mass **54**. The second sense plate **70** is attached to a second glass layer **72**, and a second outboard metallization layer **74** is attached to glass layer **72**. The glass layer **72** is also doped with conductive molecules to aid in the attachment of sense plate **70** and metallization layer **74**. An exposed glass portion **76** of glass layer **72** faces a second edge surface **58** of proof mass **54**. When power is applied to MEMS device **50**, the exposed glass portions **66** and **76** slowly collect a charge over time.

[0020] As shown in FIG. 1B, metallization layers **64** and **74** are connected to a $-V_{SB}$ line **82**, and sense plates **60** and **70** are connected to a $+V_{SB}$ line **84**. Alternatively, metallization layers **64** and **74** can be connected to $+V_{SB}$ line **84**, and sense plates **60** and **70** can be connected to $-V_{SB}$ line **82**. This symmetrical V_{AV} configuration results in the exposed glass portions **66** and **76** having the same average voltage (MID), as illustrated in the voltage diagrams. As the exposed glass portions **66** and **76** on each side of proof mass **54** achieve the same average potential over time, the effect of time-varying glass charging on the sensor capacitance is eliminated, while allowing the proof mass to have a different voltage than the exposed glass portions if desired.

[0021] FIGS. 2 and 3 are schematic depictions of a capacitive MEMS device **100** according to one embodiment, in which the present technique can be implemented. The capacitive MEMS device **100** generally includes a first sense plate **110** with an inner surface **112**, a second sense plate **120** with an inner surface **122**, and a proof mass **130** positioned between first and second sense plates **110**, **120** such that proof mass **130** faces each of inner surfaces **112** and **122**. For ease of illustration, sense plates **110**, **120** and proof mass **130** are shown offset from each other in FIG. 3, but in actual design are aligned vertically as shown in FIG. 2.

[0022] A first set of stop structures **140** is attached to inner surface **112** of first sense plate **110**. The stop structures **140** include metalized glass portions **142** coupled to inner surface **112**, and standoff portions **144** that are separated from sense plate **110** by metalized glass portions **142**. Likewise, a second set of stop structures **150** is attached to inner surface **122** of second sense plate **120**. The stop structures **150** include metalized glass portions **152** coupled to inner surface **122**, and standoff portions **154** that are separated from sense plate **120** by metalized glass portions **152**. Although a single stop structure is shown on each of sense plates **110** and **120** in FIG. 3 for clarity, it should be understood that two or more stop structures are typically located on opposite sides of each sense plate, as shown in FIG. 2.

[0023] The sense plates **110**, **120** have exposed glass layers **160** thereon, and stop structures **140**, **150** have glass layer **170** thereon. As the exposed glass layers can change potential at different locations on the stop structures, the present approach provides for the stop structures to be voltage-balanced (i.e., stop structure **150** potential matches that of proof mass **130**) to mitigate the consequences of the stop structures having a different voltage than the proof mass.

[0024] For example, during operation of MEMS device **100**, sense plate **110** has a first voltage (e.g., $-V1$), proof mass **130** has a second voltage (e.g., $+V2$) that is higher than the first voltage, and sense plate **120** has a third voltage (e.g., $V3$) that is higher than the second voltage. The standoff portions **144**, **154** are configured to have a voltage that matches the voltage of proof mass **130**, such that it is not electrically disruptive to MEMS device **100** if standoff portions **144**, **154** touch proof mass **130** during operation.

[0025] Exposed glass portions facing proof mass **130** occur at the boundaries between metalized glass portions **142** and standoff portions **144**, and at the boundaries between metalized glass portions **152** and standoff portions **154**. A plurality of voltage sources can be coupled to MEMS device **100** such that the exposed glass portions have an average voltage that is electrically neutral with respect to the voltage of proof mass **130** during operation of MEMS device **100**. In one embodiment, a first applied voltage is a positive voltage and a second applied voltage is a negative voltage, with the positive and negative voltages having the substantially the same numerical value such that the exposed glass has an average voltage that is substantially at ground.

[0026] FIGS. 4 and 5A-5B are schematic top-down depictions of a MEMS device **200** according to another embodiment. The MEMS device **200** includes a first sense plate **210**, a second sense plate **220**, and a proof mass **230** positioned between first and second sense plates **210**, **220**. While sense plates **210**, **220** and proof mass **230** are shown offset from each other in FIG. 4 for ease of illustration, these structures are in actual design aligned vertically, such as depicted for MEMS device **100** in FIG. 2. FIG. 5A shows first sense plate **210** separated from the other structures of MEMS device **200**, and FIG. 5B depicts second sense plate **220** separated from the other structures of MEMS device **200**.

[0027] As illustrated in FIGS. 4 and 5A, a first set of stop structures **240** are attached to an inner surface **212** of first sense plate **210** such that stop structures **240** face proof mass **230**. The stop structures **240** each include metalized glass portions **242** and standoff portions **244**. Likewise, as shown in FIGS. 4 and 5B, a second set of stop structures **250** are attached to an inner surface **222** of second sense plate **220** such that stop structures **250** face proof mass **230**. The stop structures **250** each include metalized glass portions **252** and standoff portions **254**. The standoff portions **244** prevent first sense plate **210** from contacting proof mass **230** during operation of MEMS device **200**. Likewise, standoff portions **254** prevent second sense plate **220** from contacting proof mass **230** during operation of MEMS device **200**.

[0028] While FIG. 4 shows four stop structures around the perimeter of each of sense plates **210** and **220**, it should be understood that one or more additional stop structures can be utilized as needed, such as in high G-force applications.

[0029] Exposed glass portions facing proof mass **230** occur at the interfaces between metalized glass portions **242** and standoff portions **244**, and at the interfaces between metalized glass portions **252** and standoff portions **254**. A plurality of

voltage sources can be coupled to MEMS device **200** such that the exposed glass portions have an average voltage that is electrically neutral with respect to a voltage level of the proof mass during operation of MEMS device **200**.

EXAMPLE EMBODIMENTS

[0030] Example 1 includes a method of controlling exposed glass charging in a micro-electro-mechanical systems (MEMS) device, the method comprising: providing a MEMS device comprising a proof mass positioned apart from at least one sense plate and at least one outboard metallization layer, wherein at least one conductive glass layer is coupled to the sense plate and the outboard metallization layer, the conductive glass layer including at least one exposed glass portion near the proof mass; and applying a first voltage to the sense plate and a second voltage to the outboard metallization layer, the first voltage separated from the second voltage by a predetermined voltage level such that the exposed glass portion has an average voltage corresponding to a voltage midway between the first voltage and the second voltage.

[0031] Example 2 includes the method of Example 1, wherein the first voltage is separated from the second voltage such that the exposed glass portion has an average voltage that is substantially at the same potential as that of the proof mass.

[0032] Example 3 includes the method of Example 1, wherein the proof mass is positioned between a first sense plate and a second sense plate, the first sense plate attached to a first conductive glass layer and a first outboard metallization layer attached to the first conductive glass layer, the second sense plate attached to a second conductive glass layer and a second outboard metallization layer attached to the second conductive glass layer.

[0033] Example 4 includes the method of Example 3, wherein an exposed glass portion of the first glass layer faces a first edge surface of the proof mass, and an exposed glass portion of the second glass layer faces a second edge surface of the proof mass.

[0034] Example 5 includes the method of any of Examples 3-4, wherein the first voltage is applied to the first and second sense plates and the second voltage is applied to the first and second outboard metallization layers, the first voltage separated from the second voltage such that the exposed glass portions each have an average voltage corresponding to a voltage midway between the first voltage and the second voltage.

[0035] Example 6 includes the method of any of Examples 3-5, wherein the exposed glass portions have substantially the same average voltages as that of the proof mass.

[0036] Example 7 includes the method of any of Examples 1-6, wherein the first voltage is a positive voltage and the second voltage is a negative voltage.

[0037] Example 8 includes the method of any of Examples 1-7, and further comprising a plurality of stop structures coupled to the sense plate.

[0038] Example 9 includes the method of any of Examples 1-8, wherein the MEMS device comprises a gyroscope or an accelerometer.

[0039] Example 10 includes a micro-electro-mechanical systems (MEMS) device, comprising: a proof mass; a first sense plate positioned apart from the proof mass; a first outboard metallization layer positioned apart from the proof mass; a first conductive glass layer coupled to the first sense plate and the first outboard metallization layer, the first conductive glass layer including at least one exposed glass por-

tion near the proof mass; a first voltage line electrically connected to the first sense plate and having a first voltage level; and a second voltage line electrically connected to the first outboard metallization layer and having a second voltage level that is different than the first voltage level; wherein the exposed glass portion has an average voltage corresponding to a voltage midway between the first voltage level and the second voltage level.

[0040] Example 11 includes the MEMS device of Example 10, wherein the first voltage level is separated from the second voltage level such that the exposed glass portion has an average voltage that is substantially at the same potential as that of the proof mass.

[0041] Example 12 includes the MEMS device of Examples 10-11, and further comprising: a second sense plate positioned apart from the proof mass opposite from the first sense plate such that the proof mass is between the first sense plate and the second sense plate; a second outboard metallization layer positioned apart from the proof mass; and a second conductive glass layer coupled to the second sense plate and the second outboard metallization layer, the second conductive glass layer including at least one exposed glass portion near the proof mass.

[0042] Example 13 includes the MEMS device of any of Examples 10-12, wherein the exposed glass portion of the first glass layer faces a first edge surface of the proof mass, and the exposed glass portion of the second glass layer faces a second edge surface of the proof mass.

[0043] Example 14 includes the MEMS device of any of Examples 10-13, wherein the first voltage line is electrically connected to the second sense plate, and the second voltage line is electrically connected to the second outboard metallization layer.

[0044] Example 15 includes the MEMS device of any of Examples 10-14, wherein the first voltage level is separated from the second voltage level such that the exposed glass portions each have an average voltage corresponding to a voltage midway between the first voltage level and the second voltage level.

[0045] Example 16 includes the MEMS device of any of Examples 10-15, and further comprising a plurality of stop structures coupled to the first and second sense plates.

[0046] Example 17 includes the MEMS device of any of Examples 10-16, wherein the MEMS device comprises a gyroscope or an accelerometer.

[0047] Example 18 includes a MEMS device comprising: a first sense plate with a first inner surface; a second sense plate with a second inner surface; a proof mass located between the first and second sense plates such that the proof mass faces each of the first and second inner surfaces; a first set of stop structures coupled to the first inner surface of the first sense plate; a second set of stop structures coupled to the second inner surface of the second sense plate; a first conductive glass layer coupled to the first sense plate and the first set of stop structures, the first conductive glass layer including at least one exposed glass portion near the proof mass; and a second conductive glass layer coupled to the second sense plate and the second set of stop structures, the second conductive glass layer including at least one exposed glass portion near the proof mass; wherein a plurality of voltage sources are coupled to the MEMS device such that the exposed glass portions have an average voltage that is electrically neutral with respect to a voltage level of the proof mass during operation of the MEMS device.

[0048] Example 19 includes the MEMS device of Example 18, wherein each of the stop structures include one or more metalized glass portions, and one or more standoff portions that are separated from the sense plates by the metalized glass portions.

[0049] Example 20 includes the MEMS device of any of Examples 18-19, wherein the standoff portions are configured to have a voltage level that matches the voltage level of the proof mass.

[0050] The present invention may be embodied in other forms without departing from its essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. Therefore, it is intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A method of controlling exposed glass charging in a micro-electro-mechanical systems (MEMS) device, the method comprising:

providing a MEMS device comprising a proof mass positioned apart from at least one sense plate and at least one outboard metallization layer, wherein at least one conductive glass layer is coupled to the sense plate and the outboard metallization layer, the conductive glass layer including at least one exposed glass portion near the proof mass; and

applying a first voltage to the sense plate and a second voltage to the outboard metallization layer, the first voltage separated from the second voltage by a predetermined voltage level such that the exposed glass portion has an average voltage corresponding to a voltage midway between the first voltage and the second voltage.

2. The method of claim 1, wherein the first voltage is separated from the second voltage such that the exposed glass portion has an average voltage that is substantially at the same potential as that of the proof mass.

3. The method of claim 1, wherein the proof mass is positioned between a first sense plate and a second sense plate, the first sense plate attached to a first conductive glass layer and a first outboard metallization layer attached to the first conductive glass layer, the second sense plate attached to a second conductive glass layer and a second outboard metallization layer attached to the second conductive glass layer.

4. The method of claim 3, wherein an exposed glass portion of the first glass layer faces a first edge surface of the proof mass, and an exposed glass portion of the second glass layer faces a second edge surface of the proof mass.

5. The method of claim 4, wherein the first voltage is applied to the first and second sense plates and the second voltage is applied to the first and second outboard metallization layers, the first voltage separated from the second voltage such that the exposed glass portions each have an average voltage corresponding to a voltage midway between the first voltage and the second voltage.

6. The method of claim 5, wherein the exposed glass portions have substantially the same average voltages as that of the proof mass.

7. The method of claim 1, wherein the first voltage is a positive voltage and the second voltage is a negative voltage.

8. The method of claim 1, further comprising a plurality of stop structures coupled to the sense plate.

9. The method of claim 1, wherein the MEMS device comprises a gyroscope or an accelerometer.

10. A micro-electro-mechanical systems (MEMS) device, comprising:

a proof mass;

a first sense plate positioned apart from the proof mass;

a first outboard metallization layer positioned apart from the proof mass;

a first conductive glass layer coupled to the first sense plate and the first outboard metallization layer, the first conductive glass layer including at least one exposed glass portion near the proof mass;

a first voltage line electrically connected to the first sense plate and having a first voltage level; and

a second voltage line electrically connected to the first outboard metallization layer and having a second voltage level that is different than the first voltage level;

wherein the exposed glass portion has an average voltage corresponding to a voltage midway between the first voltage level and the second voltage level.

11. The MEMS device of claim 10, wherein the first voltage level is separated from the second voltage level such that the exposed glass portion has an average voltage that is substantially at the same potential as that of the proof mass.

12. The MEMS device of claim 10, further comprising:

a second sense plate positioned apart from the proof mass opposite from the first sense plate such that the proof mass is between the first sense plate and the second sense plate;

a second outboard metallization layer positioned apart from the proof mass; and

a second conductive glass layer coupled to the second sense plate and the second outboard metallization layer, the second conductive glass layer including at least one exposed glass portion near the proof mass.

13. The MEMS device of claim 12, wherein the exposed glass portion of the first glass layer faces a first edge surface of the proof mass, and the exposed glass portion of the second glass layer faces a second edge surface of the proof mass.

14. The MEMS device of claim 13, wherein the first voltage line is electrically connected to the second sense plate, and the second voltage line is electrically connected to the second outboard metallization layer.

15. The MEMS device of claim 14, wherein the first voltage level is separated from the second voltage level such that the exposed glass portions each have an average voltage corresponding to a voltage midway between the first voltage level and the second voltage level.

16. The MEMS device of claim 14, further comprising a plurality of stop structures coupled to the first and second sense plates.

17. The MEMS device of claim 10, wherein the MEMS device comprises a gyroscope or an accelerometer.

18. A micro-electro-mechanical systems (MEMS) device, comprising:

a first sense plate with a first inner surface;

a second sense plate with a second inner surface;

a proof mass located between the first and second sense plates such that the proof mass faces each of the first and second inner surfaces;

a first set of stop structures coupled to the first inner surface of the first sense plate;

a second set of stop structures coupled to the second inner surface of the second sense plate;

a first conductive glass layer coupled to the first sense plate and the first set of stop structures, the first conductive glass layer including at least one exposed glass portion near the proof mass; and

a second conductive glass layer coupled to the second sense plate and the second set of stop structures, the second conductive glass layer including at least one exposed glass portion near the proof mass;

wherein a plurality of voltage sources are coupled to the MEMS device such that the exposed glass portions have an average voltage that is electrically neutral with respect to a voltage level of the proof mass during operation of the MEMS device.

19. The MEMS device of claim **18**, wherein each of the stop structures include one or more metalized glass portions, and one or more standoff portions that are separated from the sense plates by the metalized glass portions.

20. The MEMS device of claim **19**, wherein the standoff portions are configured to have a voltage level that matches the voltage level of the proof mass.

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